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A Report to

The Metropolitan Television Alliance

Regarding

Field Test Results for the New York City Prototype Distributed Transmission System

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EXECUTIVE SUMMARY

INTRODUCTION

The Metropolitan Television Alliance, LLC (**MTVA** or **"Alliance"**) was formed after September 11, 2001, when many New York City television stations' digital and analog transmission facilities were lost in the collapse of the North Tower of the World Trade Center (**WTC**). The television stations, working cooperatively under the aegis of the MTVA, quickly installed digital and analog transmission facilities on top of the Empire State Building (**ESB**) as well as other locations such as 4 Times Square and a tower in Alpine, NJ. While these facilities are the best currently available, regional broadcast from the ESB may not be the optimal solution for the distribution of digital television signals. The existing facilities are outdated, crowded and perhaps inadequate to serve as a long term home for digital broadcast by all MTVA members. And in an era of unprecedented construction in the city, new high rise buildings in the region, impede or block signals, interfering with reception and creating "shadows" that may extend across parts of the city and surrounding areas, depriving viewers of an over-the-air service.

At Empire, with a crowded antenna mast structure (originally designed as a mooring for dirigibles), many of the digital television (**DTV**) antennas were side-mounted and located at lower elevations than their previous locations on the north tower of the WTC. Physical limitations on the mast, in terms of both real estate and loading capacity, required partially-obstructed antennas at ESB. The result is that some areas in the New York City metropolitan area have DTV television coverage (signal levels) and service (reception) inferior to that which was available from the former WTC site, and, in most cases, than is currently available from the analog facilities at ESB.

On March 22, 2007 the National Telecommunications and Information Administration (**NTIA**) approved the MTVA's application for a grant to support the design and deployment of a temporary digital television broadcast system for its member stations in the greater New York City region. The program was authorized as part of The Digital Television Transition and Public Safety Act of 2005 (Title III of the Deficit Reduction Act of 2005, Public Law 109-171).

The grant application contemplated a Distributed Transmission System (**DTS**) in New York City. Distributed transmission (**DTx**) for DTV signals has been standardized by the Advanced Television Systems Committee (**ATSC**), the same standards body that defined and adopted the broadcast technology now specified by the FCC for digital broadcast in the United States. If this approach proves feasible, a system could be developed where a network of synchronized low-power transmitters are installed to augment the coverage provided from the ESB by filling in areas cast in shadow or otherwise hampered in receiving the digital signals. The MTVA membership is particularly interested in developing a system that would allow viewers currently utilizing *indoor* antennas for analog television reception to continue utilizing indoor antennas for digital television reception.

Phase One saw the MTVA deploy a small-scale prototype Distributed Transmission System to determine the viability of using this technique in a densely-built, urban environment. The Alliance tested both indoor and outdoor reception of digital television signals using set-top receivers designed in conformance with the NTIA's Coupon Eligible Converter Box (**CECB**) program. This report documents the experimental work performed under the NTIA's agreement with the MTVA and shall serve as the Alliance's report to the NTIA on the technical results of Phase One testing.

To determine if the DTS concept was feasible in this market, the MTVA has undertaken a project to deploy a small-scale (5-transmitter) *prototype* implementation of a DTx system for DTV using UHF CH 33, UHF CH 65, and high-VHF CH 12. It is anticipated that this small-scale prototype system project would enable MTVA to determine the *capability* and *feasibility* for subsequent deployment of a large-scale system using distributed transmission in New York City by the February 2009 cessation of *full-service* analog television transmissions.

To assist in this undertaking, the MTVA retained the services of John F.X. Browne & Associates, P.C., to develop strategies to augment coverage as well as design the prototype DTx network. Axcera, LLC was selected to handle the detailed system design of the prototype network, and to implement and support the prototype network on a turnkey basis. The firm of Meintel, Sgrignoli, & Wallace, LLC (**MSW**) was retained to *characterize* the receive system aspect of the project, *develop* a field test plan, and *perform* the actual field measurements.

As part of the overall DTS project, MTVA first commissioned **MSW** to complete a series of smaller projects: (1) perform anechoic chamber testing to determine the RF performance of consumer *indoor antennas* likely to be used by typical DTV viewers, (2) perform laboratory testing to determine the RF performance of two state-of-the-art consumer *DTV receivers* likely to be used by typical DTV viewers, (3) develop appropriate urban *planning factors* for the prediction of both indoor and outdoor DTV *coverage* and *service* of the New York City DTx system, (4) create a detailed DTx *field test plan*, and (5) execute the DTV *field test*, along with subsequent data analysis and documentation.

After the MTVA reviewed and approved the *initial* prototype DTS field test plan document (dated **October 31, 2007**) and completed the construction of the prototype DTx system in early January 2008, official field testing began on **January 15,**

2008 and was completed on **May 9, 2008**. This written field test report describes the DTx network design and implementation, the final field test *plan*, and the detailed data analysis of the field test *results*.

The *general* goal of the DTS field test was to use this small prototype DTx system in Brooklyn to determine the *capability* and *feasibility* of a large-scale DTx system in New York City built around the current DTV transmission site at ESB. It was important to ascertain whether an increased percentage of viewers will be able to watch over-the-air DTV after February 17, 2009 when *full-service* analog NTSC television has been turned off. While *indoor* reception was ultimately the primary interest in these field tests, a majority of the New York City field testing was performed *outdoors* due to practical considerations (i.e., the difficulty in finding a large number of indoor test site volunteers). Nevertheless, some indoor test sites were visited and evaluated along with many outdoor test sites.

The *specific* field test goals were:

Determine and compare DTV coverage, service, margin, and ease of reception (antenna adjustment range) from ESB signals on CH 12 & CH 33 ***with*** and ***without*** an active DTx network.

Determine DTV coverage and service performance of a DTx system on CH 65 with no ESB source.

Determine any RF *self*-interference effects caused by the DTx system.

SYSTEM DESIGN

The main transmitters, commercial station WPIX CH 33 and a temporary CH 12 (operating with a Special Temporary Authorization, or STA), were located at the top of ESB. The 137 kW ERP (average) CH 33 DTV signal was radiated from its side-mounted, partially-obstructed *omni*-directional antenna, while a temporary 1 kW (average) CH 12 DTV signal was radiated from a temporary *directional* antenna aimed towards Brooklyn. The 4 low-power gap filler transmitter sites were in nearby Brooklyn, and were typically within 10 miles of ESB.

The gap filler transmitters, located in a square approximately **3 miles** on a side and referred to as the Brooklyn test "box," radiated low power DTV signals (1000 W, average ERP for CH 33 and CH 65 and 100 W, average ERP for CH 12). All five DTV transmitters were synchronized and time-delay adjusted using the principles found in the ATSC A/110B Distributed Transmission Standard (see **Appendix 1**). *Most* of the gap filler transmitter antennas were omni-directional.

The goal was to provide a consistently large DTV signal level to Brooklyn using all 5 distributed and synchronized transmitters, while keeping the self-interference to a minimum and within the interference mask recommended by the ATSC A/74 guidelines.

FIELD TEST PLAN

The field test plan called for selecting a vast majority of the outdoor and indoor test sites within the Brooklyn "box," as defined by the locations of the 4 low-power gap filler transmitters. It is within this area that the overlapping signal regions exist, and careful design of the DTx network was required to avoid destructive *self*-interference. While the main goal was to evaluate *indoor* DTV reception in Brooklyn with and without DTx, a majority of the field test sites were outdoors due to the difficulty of finding appropriate indoor test site volunteers within the Brooklyn test "box."

A total of **132** test sites were visited (**109** outdoor, **23** indoor). The following is the breakdown of the MTVA field test sites:

Outdoor Test Sites (109):

80 were **"Grid"** measurements sites, *inside* the box

10 were **"Driveway"** measurement sites, *inside* the box

6 were **"Interference"** measurement sites (predicted), *outside* the box

13 were **"Driveway"** measurement sites, *outside* the box

Indoor Test Sites (23):

10 were **"Indoor"** measurement sites, *inside* the box

13 were **"Indoor"** measurement sites, *outside* the box

The outdoor test sites were measured with two separate field test vehicles (vans), each capable of hydraulically extending a mast up to 30' above ground level (**AGL**). Each vehicle was equipped with the same test equipment: a mast compass, a GPS receiver, a broadband directional log periodic antenna (high-VHF through UHF), downlead cable, a calibrated variable turret step attenuator, a preamplifier, a 4-way splitter, a spectrum analyzer (with channel-power measurement capability), an RF Watermark Identification analyzer (**TxID**), two fifth generation (**5G**) DTV receivers, and audio/video monitors.

The *outdoor* field test plan called for 12 measurement scenarios at *each* test site: <u>three</u> different RF channels (CH 33, CH 12, and CH 65) at <u>two</u> different receive antenna heights (30' AGL and 15' AGL) with <u>both</u> DTx inactive and DTx active. The basic measurements performed for each test scenario were as follows:

DTV field strength measurement (in dBμV/m) at the antenna orientation that provided a maximum (peaked) signal level.
DTV service (3 "hits" or less in 3 minutes) at the antenna orientation that provided a maximum (peaked) signal level.
Range of antenna rotation (in degrees) for acceptable DTV reception.

The *indoor* field test plan also called for 12 measurement scenarios at *each* test site: three different RF channels (CH 33, CH 12, and CH 65) using two different receive antennas (primary dipole and secondary directional) with both DTx inactive and DTx active. The same field strength, service, and range of rotation measurements were made at each indoor test site, similar to each outdoor test site. Additionally, a smart antenna was also used with each DTV receiver to evaluate its indoor performance with DTx active and inactive.

TEST RESULTS

The CH 33 *outdoor* field strength measurements at the **90** test sites within the Brooklyn "box" indicated that there were fairly consistent DTV field strength levels when the directional receive antenna angle was selected for *maximum* signal level at 30' AGL and 15' AGL. Throughout the Brooklyn "box," CH 33 DTV signals were found to be, on the average, in the range of **73 dBμV/m** (DTx OFF) to **80 dBμV/m** (DTx ON) for a 30' AGL receive antenna and they were about **3 dB** lower (DTx OFF and DTx ON) at 15'AGL. These CH 33 signal levels were not only large enough to produce SNR values (>**40 dB** for DTx OFF and >**47 dB** for DTx ON) at the receiver inputs that were above the required 15-dB white-noise threshold, but they also easily covered an additional 5 dB to 8 dB of possible noise threshold degradation due to the presence of naturally-occurring or DTx-induced multipath. The CH 33 outdoor DTV service numbers increased a modest amount from about **81%** (without DTx) to more than **85%** (with DTx). Also, significant margin and range of antenna rotation were observed at many test sites, providing *evidence* for successful long-term *outdoor* DTV service (i.e., accounting for signal level time variability) on CH 33.

Similarly, the CH 12 *outdoor* antenna-maximized field strength values were found to range between **59 dBμV/m** (DTx OFF) to **70 dBμV/m** (DTx ON) at 30' AGL, and they were about **2.5 dB** lower (DTx OFF and DTx ON) at 15' AGL, both producing a very high average SNR value. The CH 12 outdoor DTV service numbers increased a modest amount from about **75%** (DTx OFF) to **80%** (DTx ON), and significant margin and range of antenna rotation were likewise observed. This provided *evidence* for successful long-term *outdoor* DTV service on CH 12.

Finally, the CH 65 *outdoor* results with DTx active (since there was no CH 65 ESB transmitter, this was the only mode possible to test) showed that the average field strength was a strong **76 dBμV/m** at 30' AGL and **2 dB** less at 15' AGL, and produced SNR values in excess of **40 dB**. The CH 65 DTV service was a significant **94%** (Rx) and **85%** (Rx2), with respectable margins around **20 dB**. This provided *evidence* for successful long-term *outdoor* DTV service on CH 65.

Even though there were not enough *indoor* test sites within the DTx "box" for statistical relevancy, the **23** indoor test sites did provide field strength results on CH 33 that showed similar trends as the outdoor results. For the existing WPIX CH 33 commercial station operating at full allocated DTV power, with its partially-obstructed "omni-directional" antenna on ESB, the average indoor field strength value with DTx inactive for all **23** indoor test sites (including those *outside* the "box") was **69 dBμV/m.** This is a very respectable number for the average *indoor* field strength value in the New York City metropolitan area, providing an average SNR value of **38 dB** for CH 33. These **23** sites with DTx *inactive* exhibited good service (**70%** for Rx1 and **65%** for Rx2), with good margin and range of antenna rotation. Note that CH 12 and CH 65 were *not* analyzed with DTx inactive for indoor field strength using all **23** indoor test sites since (1) the CH 12 ESB transmit antenna was not omni-directional but rather directional, specifically pointing towards the Brooklyn "box," and (2) there was no CH 65 transmitter on ESB.

Analysis of all **23** indoor sites and their companion outdoor driveway sites showed that the signal attenuation experienced from outdoor to indoor averaged around **6 dB** for CH 33, which is much lower than the traditionally-presumed 10-dB to 20-dB values for two-story single-dwelling residences. However, this is partially explained by the fact that many of the **23** indoor test sites were *above* 15' AGL, and some were even above 30' AGL (i.e., test sites located on upper stories of buildings that were higher than the outdoor antenna heights used in the field test). Therefore, these attenuation results must be viewed under these special circumstances.

While all **23** indoor (and driveway) test sites were used in the CH 33 DTx-*inactive* analysis, DTx system evaluation was performed on *only* the **10** indoor test sites within the Brooklyn "box." The reason for this is that the other test sites (i.e., "outside-the-box") did *not* gain much benefit (and perhaps even experienced detrimental *self*-interference effects) from the DTx gap-filler transmitters. Any analysis that would have included the **13** "outside-the-box" test sites would have unfairly biased the results negatively for DTx evaluation since the DTx prototype test system was specifically designed to study its performance inside the Brooklyn "box."

For DTx *inactive*, the indoor field strengths at these **10** Brooklyn "box" test sites were approximately **66 dBμV/m** (CH 33) and **51 dBμV/m** (CH 12). These are very respectable field strength numbers for indoor DTV sites *without* benefit of DTx gap filler transmitters. Indoor DTV reception measurements resulted in about **65%** (CH 33) and **15%** (CH 12) service and *average* margins of **12 dB** (CH 33) and **3 dB** (CH 12).

For DTx *active*, the indoor field strengths at these **10** Brooklyn "box" test sites increased by about **7 dB** (CH 33) and **9 dB** (CH 12), meaning that these **10** sites exhibited average field strengths of about **73 dBμV/m** (CH 33) and **60 dBμV/m** (CH 12). Indoor DTV service increased to **85%** (CH 33) and **30%** (CH 12) of the test sites and the *average* margins were found to increase to approximately **17 dB** (CH 33) and **9 dB** (CH 12). As a comparison, the average CH 65 field strength with DTx active was about **65 dBμV/m**, with **90%** DTV service and an *average* margin of **16 dB**. The difference in performance between CH 33 and CH 12 is not entirely understood at this time.

An interesting side note is that the secondary *directional* indoor test antennas, which also performed well, did not do quite as well as the primary *dipole* indoor test antennas (with their figure-8 azimuth pattern). This indicates that *perhaps* the recent receiver equalizer innovations and updated algorithms now use the echoes of the signal (which typically occur more often with dipole antennas that have no front-to-back attenuation) for mitigating the multipath effect.

The two 5G DTV receivers (Rx1 and Rx2) both did well in these field tests, and are significantly better than past generations. However, it was clear that Rx1 consistently did better than Rx2 in providing service, margin, and range of rotation. While both units were 5G, Rx1's multipath equalizer apparently is a little more robust, being able to handle slightly stronger and more dynamic multipath conditions than Rx2.

CONCLUSIONS

This MTVA project, starting with the design, followed by implementation, and ending with a major field test, was a lesson in DTx system and hardware design as well as viability (i.e., feasibility). Positive small-scale prototype test results do *not* guarantee success in a massive deployment of such a system, as that depends on the specific network design that often includes a large number of factors beyond those that were tested in New York City. Further work on location and time variability would be beneficial when trying to extend these prototype results to larger metropolitan areas. However, these field test results indicate that DTx network *technology* is available today and it is viable when properly designed and implemented. Likewise, much has been learned from this field test that will guide future DTx network designs for highly urbanized metropolitan areas like New York City.

To briefly summarize the MTVA project:

1) The ATSC A/110B standard describes basic DTx synchronization theory, and has been shown to work in a major urban area, allowing multiple synchronized low-power gap fillers to improve DTV coverage (field strength) and service (reception).

2) Remote gap-filler transmitter site selection and site leasing in a major urban area are possible, although expensive.

3) System hardware design using the A/110B principles can be accomplished with current production equipment, although with additional hardware costs compared to single transmitter designs.

4) The main area of field testing (i.e., Brooklyn test "box") already had significant CH 33 *outdoor* DTV service and reasonable CH 33 *indoor* DTV service from ESB *without* DTx, thereby limiting the amount of possible service improvement due to DTx. However, when DTx was active, more substantial increases in margin (to overcome time variability) and range of antenna rotation (to allow easier antenna adjustment) were experienced. CH 12 had similar *outdoor* results, although not quite as good as CH 33. CH 12 *indoor* results were noticeably worse than that if UHF. This difference in performance between CH 12 and CH 33 is not entirely understood at this time.

5) Acceptable outdoor-to-indoor attenuation was obtained in the field test. However, it must be remembered that the outdoor-to-indoor attenuation was smaller (**6 dB**) than expected (**10 – 20 dB**) due to the test locations on upper floors (3rd floor and above) for many of the indoor test sites.

6) DTx did cause *some* self-induced interference in the overlapping regions, sometimes creating reduced service, margin, and range of antenna rotation, and in some cases a complete loss of service. However, the number of these loss-of-service occurrences was relatively small, and in the cases where it did not completely eliminate DTV service, it often still allowed acceptable receive parameters (margin > 10 dB and range of rotation > 90 degrees) for successful DTV reception. It is clear, however, that a carefully-designed DTx network can facilitate both outdoor and indoor DTV reception, and that its negative self-interference effects can be minimized with good DTx system design as well as good receive system design.

7) Automatically-adjusted *smart* antennas worked reasonably well with and without DTx, providing service comparable to the manually-adjusted antennas, although there is room for improvement regarding updating the parameters more often and in a quicker manner.

8) RF watermark technology for transmitter identification and for determining signal propagation distortion as well as relative levels and delays of distributed transmitter signals was proven useful and important in field testing the DTx system and in aiding with DTx network timing setup and verification.

9) The recent 5G (and the newer 6G) receivers are much improved over earlier generations, with the most improvement occurring in the VSB decoders and the RF tuners. However, while there are many models of 5G and 6G receivers, and they are all much improved, they will *not* all work identically in severe propagation situations.

SUMMARY

Distributed transmission for DTV signals has been proposed and standardized by the ATSC. The MTVA New York City field test has allowed the evaluation of the effectiveness of such a DTx system in a major urban area in both the UHF and high-VHF bands, and it has resulted in some much-needed information and experience. Knowledge and understanding of DTx fundamentals, as they apply to the ATSC transmission system, are essential for future DTx success. The MTVA small-scale prototype system in New York City optimized as many of the design parameters as possible, with the goal to ascertain the DTx system's effectiveness in providing this metropolitan area with acceptable outdoor and indoor DTV field strength levels, service, and margin, as well as ease of antenna adjustment. However, great care was taken to minimize any significant interference into existing analog or digital television signals. DTx networks in mountainous areas, while also important, do not have quite the same significant challenges that a major metropolitan area like New York City has, since urban areas potentially experience severe DTx-induced multipath (caused by multiple same-frequency synchronized transmitters) as well as considerable naturally-occurring multipath (caused by large buildings and other man-made structures).

While the main goal of the MTVA project was to study the performance of a scaled-down version of a widespread DTx design, an added benefit was the determination that the current commercial UHF CH 33 (WPIX) single source on ESB already provided reasonably good DTV *service* in the Brooklyn test "box." In other words, the actual measured *outdoor* and *indoor* DTV service numbers in the field test "box" from ESB alone (i.e., DTx *inactive*) were found to be good. Of course, this means that there could not be a significant increase in the number of sites serviced with DTx active. However, despite the modest service increases due to DTx, the increase in the margin and range of antenna rotation at many sites was *encouraging*. It should be noted that DTx did, in fact, cause loss of DTV service at a small percentage of sites. Nevertheless, there were many other sites where the DTx-induced degradation of margin or range of rotation still provided acceptable DTV reception conditions.

It must be remembered, however, that these DTx tests in New York City were *location* variability tests and not *time* variability tests. That is, the dynamic conditions that were encountered at many of the tests sites could become worse at certain times of the day (diurnal, such as with temperature changes that cause atmospheric inversion layers or with increased traffic flow at rush hour) and times of the year (seasonal, such as with and without foliage). Therefore, care must be taken when attempting to predict future widespread DTV service using short-term testing data on a small-scale prototype system. Long-term time-variability testing would certainly produce some of these answers.

A major outcome of the field test was the *experience* gained from designing, implementing, and testing a DTx system in a major metropolitan area. However, it is also important before deployment of any large communication network to determine the primary causes of DTV reception failure in order to better understand how to optimally design and construct a larger and improved *final* DTx network in New York City in time for the February 17, 2009 end of the *full-service* DTV transition. The resulting data from this field test will help future designers to achieve optimum DTx system designs.

Finally, consumer education regarding the retirement of the NTSC analog service is essential for the successful transition to over-the-air digital broadcast television. However, not only is it important to inform the public about the timing of the analog shutoff on February 17, 2009 and how to obtain NTIA converter coupons, but it is also vital to educate them about the "lost art" of over-the-air television reception. In addition to various DTV receivers, this includes the various types of receive support (accessory) equipment at their disposal, such as antennas, preamplifiers, coaxial cable, signal splitters, band splitters, attenuator pads, etc. It is likely that, even with DTx deployed in some form, successful DTV reception in New York City may depend on viewers having *reasonable* receive equipment properly installed in their homes. In order for broadcasters to successfully educate the public on DTV receive equipment and its proper use, they must first educate themselves regarding DTV reception in general (with or without DTx), and then familiarize themselves with high-quality consumer devices that are currently available.

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MTVA DISTRIBUTED TRANSMISSION

FIELD TEST REPORT

INTRODUCTION

After the loss of the World Trade Center (**WTC**) on September 11, 2001, many of the New York City broadcasters had to scramble quickly to obtain a *temporary* transmission site in order to provide free, over-the-air (**OTA**) television signals to the region. Subsequently, many of these broadcasters ended up with facilities on the Empire State Building (**ESB**). However, with a crowded antenna structure, many of the digital television (**DTV**) television antennas were side-mounted and located at much lower heights above average terrain (**HAAT**) than their previous locations on the north tower of the WTC. In order to coordinate the recovery effort and develop broadcast facilities to replace those that were lost at the WTC, the commercial New York City television broadcasters, along with public station WNET, created the Metropolitan Television Alliance (**MTVA**).

At Empire, with a crowded antenna mast structure (originally designed as a mooring for dirigibles), many of the digital television antennas were side-mounted and located at lower elevations than their previous locations on the north tower of the WTC. Physical limitations on the mast, in terms of both real estate and loading capacity, required partially-obstructed antennas at ESB. The result is that some areas in the New York City metropolitan area have DTV television coverage (signal levels) and service (reception) inferior to that which was available from the former WTC site, and, in most cases, than is currently available from the analog facilities at ESB.

On March 22, 2007 the National Telecommunications and Information Administration (NTIA) approved the MTVA's application for a grant to support the design and deployment of a temporary digital television broadcast system for its member stations in the greater New York City region. The program was authorized as part of The Digital Television Transition and Public Safety Act of 2005 (Title III of the Deficit Reduction Act of 2005, Public Law 109-171).

One such alternative could be to utilize a Distributed Transmission System (**DTS**) in New York City. Distributed transmission (**DTx**) for DTV signals has been proposed and standardized by the Advanced Television Systems Committee (**ATSC**). If this approach were technically feasible, a system could be developed where a network of synchronized low-power "gap filler" transmitters could be installed to augment the coverage provided from the ESB. The MTVA membership is particularly interested in developing a system that would allow viewers currently utilizing *indoor* antennas for analog television reception to continue utilizing indoor antennas for digital television reception.

Since the DTS concept has never been deployed or even field tested in a dense urban environment such as the New York metropolitan area, the MTVA concluded that it was necessary that the technology be thoroughly field tested prior to making any decision regarding its applicability for the New York City market.

To determine if the DTS concept was feasible in this market, the MTVA has undertaken a project to deploy a small-scale (5 site) *prototype* implementation of a Distributed Transmission (**DTx**) system for DTV using both UHF (CH 33 and CH 65) and high-VHF (CH 12) bands in the New York City metropolitan area. Low-VHF is *not* of any interest to the MTVA since no *full-service* post-transition DTV channels have been allocated in this television band within the New York City market. It is anticipated that this small-scale prototype system project would enable MTVA to determine the *practicality* and *feasibility* for subsequent deployment of a large-scale system using distributed transmission in New York City by the February 2009 cessation of *full-service* analog television transmissions.

To assist in this undertaking, the MTVA retained the services of John F.X. Browne & Associates, P.C., to develop strategies to augment coverage as well as design the prototype DTx network. Axcera, LLC was selected to handle the detailed system design of the prototype network, and to implement and support the prototype network on a turnkey basis. The firm of Meintel, Sgrignoli, & Wallace (**MSW**) was retained to *characterize* the receive system aspect of the project (indoor antenna testing, receiver laboratory testing, and urban planning factors), *develop* a field test plan, and *perform* the actual field measurement (as described below).

As part of the overall DTS project, MTVA first commissioned **MSW** to do a detailed study and assessment of the availability and RF performance of current consumer *indoor antennas* and current consumer *DTV receivers* likely to be utilized by typical viewers for DTV reception in this area. **While *both* outdoor and indoor reception of DTV signals is vital to broadcasters, and is covered in this report, this project was specifically focused on *indoor* reception in the UHF and high-VHF television bands from multiple, synchronized DTS sources in the dense, urban New York City environment.** Subsequent to completion of both the consumer *indoor antennas* anechoic chamber testing and the *DTV receiver* laboratory testing, MTVA commissioned **MSW** to develop appropriate urban *planning factors* that may be used in predicting both indoor and outdoor DTV *coverage* and *service* of the New York City DTx system. After completion of the planning factors, MTVA then commissioned **MSW** to create a DTx *field test plan* that described test methodology for sophisticated and thorough field testing of the prototype DTx system within New York City. Using this test plan (dated **October 31, 2007**), per MTVA directive, **MSW** began the *DTV field test* on **January 15, 2008** and completed the field test on **May 9, 2008** Shortly after this, **MSW** completed the data analysis and documentation, which is the topic of this final report.

The *general* goal of the DTS field test was to use a small prototype DTx system in Brooklyn to determine the *capability* and *feasibility* of a large-scale DTx system in New York City built around the current DTV transmission at ESB. It was important to ascertain whether an increased percentage of viewers will be able to watch over-the-air DTV after February 17, 2009 when *full-service* analog NTSC television has been turned off. While *indoor* reception was ultimately the primary interest in these field tests, a majority of the New York City field testing was performed *outdoors* due to practical considerations (i.e., the difficulty in finding a large number of indoor test site volunteers living in specific neighborhoods within Brooklyn who were willing to make their homes available all day for "invading" engineers with test equipment). Nevertheless, some indoor test sites were visited and evaluated along with many outdoor test sites.

A list of the *specific* field test goals is shown below.

Determine DTV coverage, service areas, margins, and ease of reception (antenna adjustment) from ESB on CH 12 & CH 33 ***without*** an active DTx.

Determine DTV coverage, service areas, margins, and ease of reception (antenna adjustment) from ESB on CH 12 & CH 33 ***with*** an active DTx (with 4 low-power gap filler transmitters).

Compare DTV coverage and service areas from ESB on CH 12 & CH 33 to determine percentage increase or decrease from DTx implementation.

Determine DTV coverage and service performance of a DTx system on CH 65 with no ESB source.

Determine any RF *self*-interference effects caused by the DTx system.

The following material is meant to be a *detailed* description of the MTVA's New York City prototype DTx system, the test plan and measurement equipment, and the test data results. It also includes some *general* information on the ATSC DTV system as well as distributed transmission. The DTS field test lasted *about* 4 months (mid January through early May). From this field test analysis and data results, **MTVA** can evaluate functionality and feasibility of a future *large-* scale DTx network in the New York City greater metropolitan area.

DTx PROTOTYPE SYSTEM DESIGN

OVERVIEW

The *general* DTS theory of operation described in **Appendix 1** is used as background information for the description of the *specific* MTVA prototype DTS design. This project was overseen on a daily basis by MTVA project leadership. Two *types* of field tests were performed in the New York City metropolitan area. **First**, two separate DTx tests (CH 33 and CH 12) were performed with a main transmitter operating on **ESB** and four (4) gap filler transmitters operating in the Brooklyn area on various buildings (although, the temporary CH 12 ESB transmitter radiated much lower power than the commercial CH 33 transmitter). **Second**, there was a distributed transmission test (CH 65) with no main centrally-located transmitter on ESB but instead with only four (4) Distributed Transmitters (**DTxTs**) operating from the *same* Brooklyn-area buildings as the others. (Despite the fact that the transmitters on CH 65 are *not* filling gaps in coverage from ESB, for consistency in the discussion, the four Brooklyn sites will be termed gap fillers regardless of which of the three test systems is under consideration.). The four lower power gap filler site locations were selected as part of the DTx network that was *designed* by **John F.X. Browne and Associates** and implemented by **Axcera, LLC.**

The system design included:

Selection of main DTx transmitter signal location and parameters (existing WPIX CH 33 and prototype CH 12)

Selection of four (4) remote gap filler DTx site locations in the Brooklyn area (forming corners of a "square box")

Selection of low-power remote DTx gap filler transmitter site parameters:

Channel selection: CH 33, CH 12, and CH 65

Effective Radiated Power (**ERP**)

Antenna azimuth pattern

Antenna elevation pattern

Antenna height (**AGL**)

Gap filler transmitter relative timing adjustment

Based on the MTVA design described above, the system block diagram of the prototype DTx system that was implemented in New York City during the summer and fall of 2007 is shown in **Figure 1.**

MSW then developed a DTV *field test plan* based on this small-scale DTx prototype system design that was designed and implemented by MTVA.

The details found below regarding the system design (John Browne & Associates,) the subsystem design and hardware implementation (Axcera, Inc.), and the field test plan and field test equipment (MSW) have been reviewed and accepted by MTVA and these consultants. Further details are available upon request from the MTVA.

DTx MAIN SIGNAL SOURCE

The DTV source for all transmitters originated from the Tribune WPIX studios in New York City (**220 East 42nd Street 10017**), which is about **0.5** mile ("as the crow flies") from ESB. It consisted of an encoder with service multiplexer (**Tandberg 5780** encoder and **Harris DTP** Statistical Multiplexer), which is used for normal WPIX commercial DTV service. A pair of **Axcera** DTxA2B Distributed Transmission Adapter (**DTxA**) units, which acted as the DTS control center and its backup, received the MPEG-2 transport streams from the WPIX service multiplexer. One of these two DTxA units was the *active* main unit while the other was the *passive* reserve unit. A GPS receiver (**Trak 8821A-28**) provided 10 MHz and 1-pulse/second references to the DTxA for precision synchronization.

The 19.4 Mbps MPEG-2 transport data stream at the WPIX studios, which included the inserted DTxP synchronization and control packets (see **Appendix 1** for background material), was fed from the DTxA into a (**CWDM**) fiber transmitter (1470-1610 nm) for transmission to the main transmitters (CH 33 and CH 12) at ESB as well as three of the four remote gap filler sites in Brooklyn. The remaining gap filler site (Site #3), also in Brooklyn, was fed over a microwave link using 13 GHz equipment (Microwave Radio Corporation DRP127T10AH transmitter and DRP127R10A receiver).

The DTxA synchronization control parameters developed in the DTxA unit at WPIX studios as well as the gap filler transmitter RF parameters (ON or OFF, output power level, selected timing delays, output SNR, etc.) were all remotely controlled and monitored with a PC located at WPIX studios. This was accomplished using hardware and password-protected Axess software from Statmon Technologies Corporation. In all, six different sites could be controlled and monitored in this manner (DTxA at WPIX studios, the ESB transmitter in Manhattan, and the 4 gap-filler site transmitters in Brooklyn). Furthermore, this control hardware and software could be *remotely* accessed (e.g., from one of the field test vehicles) by wirelessly accessing the local PC at WPIX studios through the Internet. The Axess software allowed control and monitoring of various parameters as shown in **Table 1**.

Table 1 IP-Based Control and Monitor Parameters

Parameter	Monitor/Control	Comments
Tx ON/OFF	Control	ESB Tx and 4 gap filler transmitters
Tx TPO	Control	Within limits of full power to half power
SFN Timing	Control	ESB Tx and 4 gap filler transmitters
Tx On-Air Status	Monitor	ESB Tx and 4 gap filler transmitters
Tx TPO	Monitor	ESB Tx and 4 gap filler transmitters
Tx SNR	Monitor	ESB Tx and 4 gap filler transmitters

DTx MAIN TRANSMITTER AND REMOTE GAP FILLERS

The main transmitter site and the four gap filler sites are illustrated in **Figure 2**, as shown on a New York City map. Note that the locations of these remote low-power transmitter sites are all in the Brooklyn area, south and southeast of ESB, and essentially form a 3-mile "square", referred to as the Brooklyn "box." The *primary* area for field testing was inside this "box", although some test sites outside the "box" were visited as well.

At ESB, the main WPIX CH 33 DTV transmitter (**Harris Diamond**) fed a side-mounted broadband UHF panel antenna array (shared by a total of 6 UHF DTV stations) that was located only about a third of the way up the ESB tower, but above the "mooring mast" that includes the 102nd floor observatory. CH 33 was radiating a **137 kWatt** *average* effective radiated power (**ERP**) DTV signal. However, New York City broadcasters felt that field strength coverage *might* be compromised from ESB due to non-optimum mounting conditions with so many antennas situated on its roof-top structure, and due to this particular antenna being partially obstructed by the body of the supporting tower. Therefore, a helicopter antenna pattern test was commissioned and then performed, which showed a distorted pattern from this side-mounted panel antenna. The *assumption* was that this antenna had back scattering from the tower structure itself that caused the effective antenna pattern *not* to be omni-directional but rather highly scalloped, which then caused non-uniform field strength levels in the nearby urban areas. This was shown to be a problem for all stations using this broadband panel antenna. It was this situation that led to the consideration of a DTx network in the New York City area to overcome this problem.

For the MTVA field test program, the Diamond transmitter was temporarily equipped with the Axcera Axciter (in lieu of the Harris exciter) to process the DTxPs (synchronization and transmitter identification control packets) and provide the DTx synchronization functionality. The configuration was such that the DTx-equipped Axcera unit was used during the testing from 8:00 am in the morning to 6:00 pm at night, and the standard Harris exciter switched back in during the rest of the time, particularly during prime-time programming. In addition to CH 33, a *low*-power CH 12 transmitter and directional antenna (aimed southeast towards Brooklyn) were temporarily installed on ESB for this DTx field test, radiating (based on an STA from the FCC) a much lower power 1000 Watt average ERP high-VHF DTV signal. However, as expected, the received CH 12 ESB signal levels measured at the Brooklyn test sites were still fairly high level due to the height of ESB and the close proximity of Brooklyn to ESB. There was *no* CH 65 transmitter at ESB in accordance with the MTVA DTx network design.

Each remote gap filler site installation had *two* low-power UHF transmitters and *one* low-power high-VHF transmitter located within two self-contained 6' tall NEMA-rated 19" rack enclosures (including associated auxiliary equipment such as a UPS system, a 2.5-ton HVAC unit for heating and cooling requirements, and a smoke detector alarm system). These cabinets (***each*** with dimensions 86" x 35" x 30" and a weight of 1250 lbs) required 240 VAC single phase, 100 Amperes per cabinet (with earth ground), and were located either outdoors on the building roof or indoors in a room near the roof top of the building. The two UHF transmitters were each rated at 250 Watts of average transmitter power output (**TPO**) while the high-VHF transmitter was rated at 10 Watts of TPO. The two independent UHF transmitters were designed for CH 33 (584 – 590 MHz) and for CH 65 (776 - 782 MHz) while the high-VHF transmitter was designed for CH 12 (204 – 210 MHz). Each DTV transmitter was outfitted with an Axcera Axciter synchronized modulator that, along with the upconverter, was configured for DTS slave mode operation. The high power amplifier (**HPA**) contained an integrated emission mask filter.

All the low-power gap filler transmitters were controlled remotely, allowing adjustment of output power level, as well as ON/OFF control. As described above, this remote control capability was accomplished by use of a password-protected IP-based web interface that allowed a user to remotely access the controller via a URL on the Internet. Each gap filler site had a unique IP address that allowed authorized connection of all 4 remote transmitter sites. Therefore, RF parameters such as TPO/ERP and ON/OFF operation could be controlled remotely, and the status of each low-power transmitter could be monitored as well. See **Table 1** for a summary of available monitor and control parameters.

Each gap filler transmitter site also had a GPS receiver (**Trak 8821A-28**) that provided a stable and locked 10 MHz reference frequency signal and a 1 pulse/second timing signal for each synchronized VSB transmitter. The 10 MHz reference signal removed any frequency offsets between the various DTx transmitters, and the 1 pps reference signal allowed precise signal timing among all these slave DTx transmitters.

Table 2 contains the pertinent transmitter information for the DTx network.

Note that according to the FCC's special temporary authorization (**STA**), the gap filler antennas could be essentially omni-directional units and the gap filler transmitters could have *maximum* ERP values of 1 kW. However, as can be seen from **Table 2**, all of the CH 12 high-VHF antennas as well as the Site 3 UHF CH 33 and CH 65 UHF antennas had cardioid azimuth patterns. The installed UHF transmitters had only 250 W maximum TPO, with the antenna providing the necessary gain to reach the maximum ERP value. The actual TPO of each transmitter was capable of being adjusted downward during testing if the need had arisen, although this was *not* necessary during the testing.

Table 2 DTx Transmitter Information

Transmitter Status	Location Address	Location Latitude Longitude	Distance from Main ESB Tx (miles)	HAMSL (meters)	Pointing Angle (deg)	Antenna Model # Beam Tilt	CH #	Tx ERP (W)
Main (ESB)	350 Fifth Ave. New York, NY 10118	40-44-54 73-59-10	0.00	335.0	145	Scala Directional HDCA-5/URM 0 degrees	12	1,000
Main (ESB)	350 Fifth Ave. New York, NY 10118	40-44-54 73-59-10	0.00	410.0	Omni	"*Omni*" Panel Harris Delta Star 0.75 degrees	33	137,000
Gap Filler 1	16 Court St. Brooklyn, NY	40-41-36.7 73-59-29.0	3.83	152.8	131	Scala Cardioid DRV-1/2HW (CH 12) Jampro Omni JL-SS-8-OM (CH 33) Scala Omni SL-8 Paraslot (CH 65) 0° (CH 12) /3.0° (CH 33/65)	12 33 65	100 1,000 1,000
Gap Filler 2	95 Evergreen Brooklyn, NY	40-41-59.3 73-55-57.7	4.37	43.3	221	Scala Cardioid DRV-1/2HW (CH 12) Scala Omni SL-8 Paraslot (CH 33/65) 0° (CH 12) /2.0° (CH 33/65)	12 33 65	100 1,000 1,000
Gap Filler 3	730 Linden Brooklyn, NY	40-39-12.7 73-55-54.1	7.15	33.1	311	Scala Cardioid DRV-1/2HW (CH 12) Scala Cardioid 4DR-8-3HC (CH 33/65) 0° (CH 12) / 0° (CH 33/65)	12 33 65	100 1,000 1,000
Gap Filler 4	Bishop Ford High School	40-39-20.7 73-58-56.16	6.39	69.1	40	Scala Cardioid DRV-1/2HW (CH 12) Scala Omni SL-8 Paraslot (CH 33/65) 0° (CH 12) /3.0° (CH 33/65)	12 33 65	100 1,000 1,000

Compliant with the ATSC DTx A/110B standard (**Ref A1-4**), each of the 5 distributed transmitters had a *unique* RF watermark transmitter identification (**TxID**) added to its output signal in the form of a binary spread-spectrum Kasami code sequence, as shown in **Appendix 2** and described in **Appendix 1**. This special sequence is transmitted 30 dB below the total *average* DTV signal power (in 6 MHz) and, therefore, it had negligible effect on consumer DTV receivers. This "bury ratio" is selectable in the exciter hardware, but 30 dB was deemed to be a reasonable value for the MTVA field test. This additional 2-VSB in-band RF watermark signal, which was clocked (in phase) at the 8-VSB symbol rate and synchronized with the 8-VSB field sync for robust and quick lockup, minimally affected (< 0.2 dB) the white noise thresholds of DTV receivers. These maximal-length *binary* sequences are repeated *approximately* 4 times for every one 8-VSB data field, but are *not* transmitted during the data field syncs. They are also referred to as buried spread spectrum (**BSS**) sequences since they are transmitted at power levels well below the host signal's average power level. These Kasami code sequences were selected since they exhibit excellent orthogonality (i.e., uniqueness) between all the various possible transmitter codes, and they have a code gain of more than 50 dB, which means that an RF watermark buried "only" 30 dB below the DTV signal can be "raised up" (using powerful correlation methods and averaging techniques) to about 20 dB above the DTV signal level, and therefore can accurately extracted for use as a <u>relative</u> *timing* and *power* indicator as well as a *channel impulse response* indicator. This means that, after signal processing an RF watermark signal that is buried 30 dB below the DTV signal, there remains a theoretical 20 dB measurement range for determining the levels of other synchronized transmitters, although a more practical limit would be around 12- 15 dB depending on the desired measurement accuracy that is required.

Relative DTx transmitter timing measurements in this field test were accomplished by using a *prototype* Hutech TxID RF Watermark receiver (one in *each* of the two field test trucks) that decoded the low-level RF watermark signals inserted "underneath" *each* synchronized 6 MHz DTV signal. These prototype receivers allowed reasonably precise <u>relative</u> signal *amplitude* and *timing* measurements among the transmitted ESB and gap filler signals for field test documentation. The relative timing measurement provided a means for initial timing adjustment of the DTx system as well as remote field test site documentation of the actual relative signal arrival times. An advantage of using the RF watermark receivers is that the timing relationship between the various DTx signals at a receive site could be measured while leaving the main signals from ESB active (i.e., without turning off either CH 33 or CH 12). Since the main WPIX CH 33 ESB signal could not be interrupted since it was an operating commercial DTV station, measurement of the relative signal levels and timing at every test site from each of the DTx network transmitters was reasonably determined from these RF watermark codes. Likewise, the TxID receiver was also able to determine the propagation effects of each transmitted signal (i.e., the propagation impulse response).

DTS SYNCHRONIZATION

In addition to the specifications for the DTxA that are both *explicit* and *implicit* in the ATSC A/110B standard, there are certain constraints as well as some flexibility that derive from the specific hardware implementation of the DTxA supplied by Axcera for this MTVA field test. The differences in requirements and operation from the A/110B standard are included in the discussion that follows. This discussion *assumes* the use of the GPS mode of operation by both the DTxA (at ESB) and all the remote DTx exciters (at the remote gap filler transmitter sites), as described in ATSC A/110B standard.

In the MTVA prototype DTx system, synchronization is required for 5 transmitters on CH 33 (one main and 4 gap fillers), five transmitters on CH 12 (one main and 4 gap fillers), and 4 transmitters on CH 65 (only four gap fillers since there was no existing transmitter on ESB for this particular field test). In order to maintain proper synchronization of symbol clock, trellis-coding, and signal delay among the main transmitter and all the gap fillers, an MPEG-transport link <u>must</u> exist among them as defined in the ATSC A/110B DTx standard **(Ref A1-4)**. While there are various means to create such a link (fiber, microwave, satellite, etc.), the one originally selected for the MTVA DTx prototype system test was fiber service. This fiber link carried the DTV transport packets from the WPIX studios, where the DTxA controller and the baseband encoders (video and audio) with integrated service multiplexer resided, to the transmitters at ESB and the four gap filler sites. The following link requirements were necessary:

1) The frequency and drift specs of this link must meet the SMPTE 310M standard of ±2.8 ppm frequency tolerance and ±0.028 ppm frequency drift tolerance.
2) The total *delay* between the data leaving the DTxA and reaching the exciter's SMPTE 310M input must be less than 950 msecs (i.e., essentially less than one second).
3) Total end-to-end peak-to-peak delay variation (timing error) must not exceed 3.3 msecs, with a maximum rate of *change* dictated by the SMPTE 310M specification.
4) Unbuffered packet switched data networks, where the data stream is interrupted, will *not* meet the SMPTE 310M stream specs and are therefore to be avoided.

However, some potentially serious fiber installation schedule delays at Gap Filler Site 3 during the fall of 2008 forced the use of a 13 GHz (12900 – 12925 MHz) microwave MPEG transport link between ESB and that particular site.

In general, there are two requirements for synchronization precursor packets in the DTxA input stream from the service multiplexer, as described in detail in **Appendix 1**. One is for the insertion of a 188-byte "blank" or "precursor" Distributed Transmission Packet **(DTxP)** packet and the other is the insertion of an *occasional* null packet (for purposes of slight data clock frequency adjustment). The DTxP precursors are typically sent in the MPEG transport data stream from the DTV service multiplexer to the DTxA at least *once per second* in this particular DTx network design. They are ultimately replaced in the DTxA with the necessary information required to synchronize all the transmitters. This one-second repetition rate is reasonable as it occurs often enough to quickly resynchronize the system should a "glitch" knock the system out of sync yet not so often that it significantly reduces the net data throughput. According to the ATSC A/110B standard, each DTxP packet can update up to 16 slave transmitters.

The DTxP precursor, which is like any other MPEG transport packet in that it is 188 bytes long and starts with the usual 47hex sync byte, is followed by an ATSC-assigned PID of 0x1FFA. Therefore, the first 4 bytes of the precursor DTxP comprise a normal MPEG transport stream packet header with defined parameter values. Since the DTxP is a *version* of an ATSC-defined Operations &Maintenance packet **(OMP)**, the header's fifth byte is 00h that indicates the <u>type</u> of OMP application. The rest of the packet data bytes from the service multiplexer are irrelevant, and are typically just set to 0x00 since the downstream DTxA hardware removes the zero bytes and inserts into the DTxP the proper synchronization and miscellaneous control data into the DTxP that is needed by the slave transmitters.

Table 3 contains the required byte definitions of the *precursor* DTxP transmitted from the service multiplexer to the Axcera DTxA during the MTVA DTx field test.

Table 3 Service Multiplexer DTxP Precursor Description: Byte Definitions

Packet Type	Byte #	Packet Data	Related Comments
Header	1	0x47	MPEG-2 Transport Stream Sync
Header	2	0x1F	Transport_Error_Indicator (1 bit) = 0b (no error) Payload_Unit_Start_Indicator (1 bit) = 0b ( ) Transport_Priority (1 bit) = 0b ( ) DTxP PID (upper 5 bits) = 11111b
Header	3	0xFA	DTxP PID (lower 8 bits) = 11111010bA
Header	4	0x10	Transport_Scrambling (2 bits) = 00b Adaption_Field_Control (2 bits) = 00b Continuity_Counter (4 bits) = 0001b
Payload	5	0x00	OMP_type = 0 (8 bits) = 00000000b (Tier 0 DTx)
Payload	6-188	0x00	Zero filler for remaining bytes (to be replaced in DTxA)
TOTAL	**188 bytes**	-----	**Standard MPEG-2 transport stream standard architecture**

Occasional *standard* null packets (packet ID of 0x1FFF) were inserted, on the order of approximately three every million packets or so (which is about two per minute), allowing the DTxA to remove any frequency difference in the transport stream between the service multiplexer and the DTxA by dropping null packets. Of course, the DTxA could have also *added* packets, if necessary, to the transport data stream when it was necessary to shift the data rate in the opposite direction.

DTV RECEIVERS

Two set-top boxes from well-known consumer manufacturers were selected as the DTV receivers to be used in the MTVA outdoor and indoor field tests, generically referred to as **Rx1** and **Rx2**. Both units were compliant with the mandated specifications set forth by the National Telecommunications & Information Administration (**NTIA**) for digital-to-analog (**D/A**) converter boxes to be sold under their federal coupon eligible converter box (**CECB**) program. Per NTIA certification requirements, these units were designed to receive ATSC RF signals on RF Channels 2 – 69, and perform VSB decoding (including equalization and error correction). Likewise, they also performed MPEG-2 video decoding and down-conversion to 480I standard definition video, Dolby AC-3 decoding and conversion to stereo. They also provided both CH 3/4 RF outputs and baseband composite video signals as well as line-level audio left/right outputs for connection to a legacy NTSC television set. These units came with remote control units for ON/OFF, channel change, menu selection, and other control and display functions.

These DTV receivers were characterized for RF performance during lab tests conducted previously at **MSW** facilities. Although not exactly identical in RF performance, these units were both shown to be at least 5th generation in nature and typical of what might be expected to exist in viewers' homes in the near future, and therefore were deemed appropriate for the MTVA DTx field test.

FIELD TEST EQUIPMENT SYSTEM DESIGN

OUTDOOR FIELD TEST EQUIPMENT SYSTEM DESIGN

Figure 3 illustrates the outside and inside of the two DTV field test vehicles (one belonging to **MSW** and the other to Univision) utilized in the MTVA New York City *outdoor* field test. Each truck had the ability to extend a hydraulic mast to 30' above ground level (**AGL**) and provided enough AC power from the on-board generator to operate all the test equipment.

Figure 4 contains a single block diagram of the equipment that was used in the two field test vehicles since *each* truck was essentially identical with regard to DTV signal measurement and reception capability. This truck design was based on the DTV Station Project field test vehicle design (**Ref 1**) from the late 1990s. However, it contained *updated* components and features. It was designed as a 50-Ohm *professional* installation for measurement purposes, and not a 75-Ohm *consumer* installation that would be found in typical home systems. Note that each field test truck utilized a broadband calibrated directional log periodic antenna, RG-214 double-shielded coaxial downlead cable, variable RF attenuator, robust amplifier distribution system, measurement instrumentation containing a spectrum analyzer with band-power measurement capability and RF Watermark transmitter identification (**TxID**) receiver/decoder, and two typical 5G DTV receivers (NTIA-approved D/A converter boxes).

Table 4 lists all of the pertinent equipment contained in each field test truck with its associated logistical information.

Table 4 Field Test Equipment Description

Item	Manufacturer	Part #	Item Description
Antenna (outdoor)	AH Systems	SAS-512-2	50 Ω, log periodic, VSWR<2.5; F/B>23 dB; 33L"x30"W
Antenna (indoor)	AH Systems	Model FCC-3	50 Ω,, calibrated VHF dipole, adjustable, ± 1 dB, (cal 3/11/08)
Antenna (indoor)	AH Systems	Model FCC-4	50 Ω,, calibrated UHF dipole, adjustable; ± 1 dB, (cal 3/11/08)
Antenna (indoor)	Zenith	Silver Sensor	Passive, UHF log periodic indoor antenna
Antenna (indoor)	Winegard	Sharpshooter	Active, VHF/UHF combination indoor antenna
Antenna (indoor)	Funai	DTA-5000	Active, smart UHF antenna, CEA 909 interface
Coaxial Cable (Truck #1 & #2)	Belden	RG-214	50 Ω, double-shielded, low-loss cable
Coaxial Cable (Indoor)	Belden	RG-58	50 Ω, single-shielded
Bandpass Filter #1	Microwave Filter	3160	CH 12 Bandpass filter, 50 Ω, 10 MHz 3-dB BW, N-connector
Bandpass Filter #2	Microwave Filter	3278 (4)	CH 33 Bandpass filter, 50 Ω, 10 MHz 3-dB BW, N-connector
Bandpass Filter #3	Microwave Filter	3278 (4)	CH 65 Bandpass filter, 50 Ω, 10 MHz 3-dB BW, N-connector
Variable Attenuator	JFW	50DR-001	50 Ω, 0-110 dB, 1-dB steps 1 W, BNC, VSWR≤1.4 @ 1 GHz
Fixed Attenuator Pad	Pasternack	PE-7001-3	3-dB pad for preamplifier input; 1 W, N-connectors
Preamplifier	Mini-Circuits	ZFL-1000VH	20 dB gain min, IP3=+38 dBm; NF=4.5 dB; P_{1dB}=+25 dBm
4-way Splitter	Mini-Circuits	ZFSC-4-1	Approx. 7 dB loss
DC Power Supply	Lambda	LND-2-152	Linear 15 Vdc supply; > 0.5 A
Spectrum Analyzer	Rohde & Schwarz	FSH-3	3 GHz, channel power markers, internal pre-amp, 5-dB steps
TxID RF Watermark Analyzer	Hutech	Prototype	Terrestrial watermark analyzer with companion PC software (x2)
DTV Receiver #1	-----	Prototype	NTIA prototype with remote control smart antenna interface
DTV Receiver #2	-----	Prototype	NTIA prototype with remote control smart antenna interface
Video Monitors (Truck #1)	Marshall Electronics	V-R102DP-HDA	*Dual*, 10.4" TFT flat-panel LCD monitors; multiple inputs
Video Monitors (Truck #2)	Sony Electronics	Trinitron	*Single*, 8" flat-panel CRT monitors (x2)
Video Monitors (Indoor #1)	Audiovox	PLV16081	8" LCD display, ATSC/NTSC tuner, internal speaker, headset jack
Video Monitors (Indoor #2)	Audiovox	PLV16081	8" LCD display, ATSC/NTSC tuner, internal speaker, headset jack
GPS Receivers	Garmin	GPS-76	Handheld integrated GPS receiver; Battery + ext power supply (x2)
External GPS Antenna	Garmin	GA-27C	Low profile External GPS Antenna
Laptop Computer (Truck #1)	Hewlett-Packard	NX9420	>1.2GHz processor; >256 MB RAM; >40 GB hard drive;
Laptop Computer (Truck #2)	Dell	Vostro 1500	>1.2GHz processor; >256 MB RAM; >40 GB hard drive;
USB Memory Drive	Memorex	Traveldrive	8 GB; for memory backup & archiving
Mast-mounted Compass	Raymarine	ST-40	Flux-gate compass; and electronic display; auto-correction
Operating System	Microsoft	Windows XP	Professional version;
Spreadsheet	Microsoft	Excel	Customized spreadsheet from **MSW**
US Map Program	Delorme	Street Atlas 2007	Standard map program
Spectrum Analyzer Software	Rohde & Schwartz	Flashview (FSHView)	FSH-3 control software

The *outdoor* receive antenna was a calibrated SAS-512-2 *professional* 50-Ohm log periodic antenna from A.H. Systems. This robust antenna was constructed of lightweight aluminum and manufactured to ensure maximum gain, low VSWR, and high power-handling capabilities, and had a 50-Ohm N connector. The antenna had a gain of approximately **5.5/6.5/7.2 dBi** (equivalent to **3.3/4.3/5.0 dBd**) at CH 12, CH 33, and CH 65, respectively.

The professional downlead coaxial cable was rugged RG-214, and was 50-Ohm, double-shielded, low-loss cable that was contained within a plastic Nycoil sheath for protection. The coaxial cable utilized 50-Ohm N-connectors at each end.

The truck system design utilized a professional *active* RF distribution system (i.e., not one that would be found in a consumer's home). The heart of this distribution system was the "works-in-a-drawer" (**WIAD**). **Figure 5** illustrates the WIAD's internal amplifier design, which provided variable input signal attenuation, signal amplification, and 4-way signal splitting. The truck's overall signal *sensitivity* was determined by the front-end amplifier's noise figure (along with the antenna gain and downlead loss) since there was enough system gain to overcome the noise floor of the following 5G DTV receivers, spectrum analyzer, and RF watermark receiver. This truck system gain not only determined the DTV reception sensitivity, but it also helped to provide absolute and relative signal strength measurement *accuracy* by reducing the effects of the noise floor of the spectrum analyzer and the RF watermark measurement devices. Such an arrangement allowed *simultaneous* signal level and RF watermark measurements as well as *simultaneous* DTV reception determination (i.e., service) of both DTV receivers. An *optional* bandpass filter (for CH 33, CH 65, or CH 12) was inserted (only when required) in front of the truck amplifier in situations where strong adjacent channel interference was limiting measurements and reception. **Figure 6** illustrates the magnitude response for each of these bandpass filters.

Note that the rotary RF attenuator was the *first* component in the distribution system unit, and was used to adjust the truck's amplifier *output* level (e.g., nominally adjusted for -50 dBm/6 MHz). This attenuator allowed the same truck amplifier to be used at *any* field location (close or far, line-of-sight or path-obstructed) regardless of the incoming signal level since it protected both the amplifier and the following measurement and reception devices from signal overload. The value of this attenuator was recorded in the data spreadsheet so that it was accounted for in the field strength calculation. If additional front-end overload protection was required, an *optional* bandpass filter (described above) was placed at the amplifier input. The RF amplifier was very robust (+34 dBm IP3) with ample gain to insure that the truck's noise floor was measurable above that of the spectrum analyzer and yet not be easily overloaded due to large undesired analog and digital television signals at its input. A fixed 3-dB pad on the input to the amplifier increased the 4-dB nominal amplifier noise figure to about 7 dB for the receive system, which is equal to the FCC planning factor for the UHF band (FCC planning factors assume a 10 dB noise figure value for VHF channels). A 4-way splitter inside the WIAD split the signal for simultaneous distribution to (1) the spectrum analyzer (signal *power* measurements), (2) the RF watermark receiver (DTx signal identification as well as relative *amplitude* and *timing* measurements), and (3) 5G DTV receiver Rx1 for its service measurement, and (4) 5G DTV receiver Rx2 for its *service* measurement. A shared control computer for the spectrum analyzer and the RF watermark receiver was utilized in the trucks.

Simultaneous signal measurement (for both spectrum and TxID analyzers) and DTV reception (for both 5G receivers) not only saved measurement time by allowing *parallel* operation, but it also allowed *real-time* observation of dynamic propagation conditions (signal level fading or dynamic multipath) that could not have been achieved if a *sequential* measurement process was performed. However, this type of active measurement philosophy did *not* account for typical mismatch conditions between receiving antenna and DTV tuner that might exist with an actual consumer implementation, nor did it account for the entire dynamic signal range of the two 5G receivers. Therefore, not every receiving condition was simulated in these field tests. Any concerns about receiver mismatches (with the antenna and downlead cable) and degraded sensitivities (due to increased noise figures from mismatched source impedances) must be accounted for by theoretically applying such conditions to the field test *results* in the form of reduced margins. While the use of an active antenna (or a passive antenna with an active distribution system, as used in the MTVA field test) can possibly improve the sensitivity over that of a pure passive antenna, the measured signal levels obtained during the DTS field test in New York City were not weak, but rather strong, and there typically was not a concern about sensitivity. In situations such as this in the future, passive antennas may be used, eliminating the possibility of amplifier overload that causes cross-modulation and intermodulation distortion. These passive antennas may supply enough signal strength for successful DTV reception, provided that any signal multipath can be handled by the DTV receiver's equalizer. As will be seen in a subsequent section, the *indoor* field test plan also called for an active distribution scheme for the tests.

Field strength (rms value over 6 MHz bandwidth) was *calculated* based on the total average power (in 6 MHz) that was measured by the spectrum analyzer (using band-power markers) in the truck. The wavelength at the DTV channel center frequency was used in the field strength calculations. The gain of the WIAD, the loss of the downlead coaxial cable, and the loss of the variable attenuator established the overall truck system gain. This truck system gain, coupled with the frequency-dependent dipole factor and antenna gain (certified by the antenna manufacturer), all played a role in the calculation of the DTV field strength at the antenna input (see **Figure 4** for the field strength equation). Calibration of the truck system gain was measured and recorded *each* day prior to the start of testing. Note that if the signal level at a field test site was varying, an estimated average value was recorded, along with a comment indicating the approximate amount of signal level variation.

INDOOR FIELD TEST EQUIPMENT SYSTEM DESIGN

The MTVA DTx indoor testing, like any other indoor field test, was a challenging task since it was desired to minimize the amount of test equipment that was needed to be carried into someone's home and yet maximize the amount of data that was capable of being gathered in a reasonably short period of time. Also, the ease and speed with which the equipment could be set up and torn down was crucial for minimum intrusion to the homeowner who provided personal living space for a considerable amount of time (approximately an entire weekday).

The equipment, shown in the pictures in **Figure 7**, was configured similarly to the outdoor truck system. The block diagram for the indoor test setup is similar to that used for the outdoor test setup in **Figure 5**. With the exception of the antenna and the dual video displays, the indoor test equipment was *identical* to that used in one of the trucks, except that it was removed from the truck's 19" rack system and mounted in two portable short 19" racks that were carried from the truck to inside the test home. Therefore, most of this equipment served double duty for *both* outdoor measurements and indoor measurements. The *primary* indoor receive antenna was a bi-directional ("figure-8" azimuth pattern) calibrated dipole antenna (one antenna for high-VHF and another antenna for UHF) and the two *secondary* antennas were a directional Sharpshooter for VHF and a directional Silver Sensor for UHF. These antennas were individually mounted on tripods to facilitate height and azimuth adjustment, as shown in **Figure 7**. Similar to the outdoor test setup, these antennas fed a portable amplifier/splitter unit (with variable input attenuation) that supplied the spectrum analyzer, the RF watermark test equipment, and the two 5G DTV receivers. Indoor field strength was calculated in the same manner as it was for outdoor measurements. Small video monitors (different ones than those used in the truck) for each receiver were also present in the portable rack in order to determine successful DTV reception, along with a shared control computer for the spectrum analyzer and the RF watermark receiver.

For the special case that used a smart UHF antenna system, a smart antenna was likewise mounted on a tripod (see **Figure 7**) and connected directly to one DTV receiver at a time since only one receiver can control a smart antenna. Field strengths at each test channel were *assumed* to be the same as that measured by the primary dipole antennas before the smart antenna *receiver test was performed.*

FIELD TEST PLAN DESIGN AND IMPLEMENTATION

MTVA retained **MSW** to create a field test plan based specifically on the MTVA DTS design described above, with input from and approval by the MTVA group and their other consultants. The fundamental goal of the DTx field test was to evaluate operation of the New York City *prototype* DTx network, primarily in the Brooklyn area. The details of the system design and the desired system test were originally recorded in the MTVA Field Test plan (dated **October 31, 2007**). No DTS design parameters were changed by **MSW**, but rather **MSW** conducted the New York City (Brooklyn) DTx field test using the original DTx system design. The field test plan called for at least **100** *outdoor* sites, of which at least **20** were to have corresponding *indoor* sites of varying conditions. This field test plan used elements of past DTV field test plans (**Ref 2, 3, 4, and 5**) from various industry groups (e.g., Grand Alliance, ACATS, DTV Station Project, and ATSC), with procedural modifications that accounted for the new features of a distributed transmission system.

For some readers of the report, the following definitions used in these MTVA field tests may be helpful:

Coverage: field strength value (in dBμV/m) as *calculated* from measured total average power (in 6 MHz).

Service: 3 "hits" or fewer in the DTV *video* for 3 minutes are considered acceptable.

Dynamic signal conditions: RF signal *varying* by more than ±3 dB (including due to traffic or airplanes).

OUTDOOR FIELD TEST OBJECTIVES

The primary *outdoor* field test objectives were:

Determine CH 33 *maximum field strengths* at 30' AGL and 15' AGL with ESB ON and all gap fillers **OFF** to ascertain coverage, service, and margin of ESB UHF transmitter by itself.

Determine CH 33 *maximum field strengths* at 30' AGL and 15' AGL with ESB ON and all gap fillers **ON** to ascertain coverage, service, and margin of a UHF DTx system.

Determine CH 12 *maximum field strengths* at 30' AGL and 15' AGL with ESB ON and all gap fillers **OFF** to ascertain coverage, service, and margin of ESB high-VHF transmitter by itself.

Determine CH 12 *maximum field strengths* at 30' AGL and 15' AGL with ESB ON and all gap fillers **ON** to ascertain coverage, service, and margin of a high-VHF DTx system.

Determine CH 65 *maximum field strengths* at 30' AGL and 15' AGL with all gap filler transmitters **ON** to ascertain coverage, service, and margin of a UHF "distributed transmitter" system (i.e., one in which there is no high-power main transmitter).

Determine CH 33 *range of antenna rotation service* at 30' AGL and 15' AGL from ESB with and without gap fillers to ascertain ease of adjustment and determine any cause of failure throughout the range of antenna rotation.

Determine CH 12 *range of antenna rotation service* at 30' AGL and 15' AGL from ESB with and without gap fillers to ascertain ease of adjustment and determine any cause of failure throughout the range of antenna rotation.

Determine CH 65 *range of antenna rotation service* at 30' AGL and 15' AGL with only gap filler transmitters to ascertain ease of adjustment and determine any cause of failure throughout the range of antenna rotation.

Note that each of these *outdoor* tests was performed on CH 12, CH 33, and CH 65 at two antenna heights above ground level (30' AGL and 15' AGL) using one broadband log periodic antenna that covers the entire high-VHF and UHF television bands.

INDOOR FIELD TEST OBJECTIVES

The primary *indoor* field test objectives, similar to the outdoor objectives, were:

Determine CH 33 *maximum field strengths* with a primary (dipole) antenna and a secondary antenna (directional) with ESB ON and all gap fillers **OFF** to ascertain coverage, service, and margin of ESB UHF transmitter by itself.

Determine CH 33 *maximum field strengths* with a primary (dipole) antenna and a secondary antenna (directional) with ESB ON and all gap fillers **ON** to ascertain coverage, service, and margin of a UHF DTx system.

Determine CH 12 *maximum field strengths* with a primary (dipole) antenna and a secondary antenna (directional) with ESB ON and all gap fillers **OFF** to ascertain coverage, service, and margin of ESB high-VHF transmitter by itself.

Determine CH 12 *maximum field strengths* with a primary (dipole) antenna and a secondary antenna (directional) with ESB ON and all gap fillers **ON** to ascertain coverage, service, and margin of a high-VHF DTx system.

Determine CH 65 *maximum field strengths* with a primary (dipole) antenna and a secondary antenna (directional) with all gap filler transmitters **ON** to ascertain coverage, service, and margin of a UHF "distributed transmitter" system (i.e., one in which there is no high-power main transmitter).

Determine CH 33 *range of antenna rotation service* with a primary (dipole) antenna and a secondary antenna (directional) from ESB with and without gap fillers to ascertain ease of adjustment and determine any cause of failure throughout the range of antenna rotation.

Determine CH 12 *range of antenna rotation service* with a primary (dipole) antenna and a secondary antenna (directional) from ESB with and without gap fillers to ascertain ease of adjustment and determine any cause of failure throughout the range of antenna rotation.

Determine CH 65 *range of antenna rotation service* with a primary (dipole) antenna and a secondary antenna (directional) with only gap filler transmitters to ascertain ease of adjustment and determine any cause of failure throughout the range of antenna rotation.

Determine CH 33 and CH 65 service for a smart antenna from ESB with and without DTx active.

DATA RECORDING AND DOCUMENTATION

The *outdoor* field test data was gathered and recorded in ***two*** detailed Excel spreadsheet files, one for each field test truck (crew), and was used for later data analysis and archiving. These two spreadsheets were identical to each other in format, with just the data entered from each truck being different. Within each spreadsheet, there were 10 worksheets representing 12 different sub-tests of the outdoor field test (2 antenna heights times 3 RF channels times 2 DTx ON/OFF modes):

30' Peak Data (outdoor antenna @ 30' AGL rotated for maximum signal strength for *both* DTx inactive & active)

30' Rx1 DTx OFF (outdoor antenna @ 30' AGL range of antenna rotation for DTV receiver #1 with DTx inactive)

30' Rx2 DTx OFF (outdoor antenna @ 30' AGL range of antenna rotation for DTV receiver #2 with DTx inactive)

30' Rx1 DTx ON (outdoor antenna @ 30' AGL range of antenna rotation for DTV receiver #1 with DTx active)

30' Rx2 DTx ON (outdoor antenna @ 30' AGL range of antenna rotation for DTV receiver #2 with DTx active)

15' Peak Data (outdoor antenna @ 15' AGL rotated for maximum signal strength for *both* DTx inactive & active)

15' Rx1 DTx OFF (outdoor antenna @ 15' AGL range of antenna rotation for DTV receiver #1 with DTx inactive)

15' Rx2 DTx OFF (outdoor antenna @ 15' AGL range of antenna rotation for DTV receiver #2 with DTx inactive)

15' Rx1 DTx ON (outdoor antenna @ 15' AGL range of antenna rotation for DTV receiver #1 with DTx active)

15' Rx2 DTx ON (outdoor antenna @ 15' AGL range of antenna rotation for DTV receiver #2 with DTx active)

Some *measured* data was entered into various columns, with each row pertaining to a particular test site and DTV RF channel while other data was *calculated* in the spreadsheet. Some of the various general types of data recorded and calculated are described below:

Site name and number (Grid, Interference, Driveway, Indoor, along with specific site number)

Site location & description (address, GPS latitude and longitude coordinates, distance & bearing to each transmitter)

Test conditions (CH #, CH frequency, antenna gain, date, time of day, weather)

Truck parameters (system gain, noise floor, spectrum analyzer noise floor, input attenuation, use of bandpass filter)

Signal power and antenna bearing (for maximum signal level and range of rotation)

Calculated field strength & SNR (for maximum signal level and range of rotation)

Plot filenames (spectrum and RF watermark)

DTV service for *each* receiver over 3-minute period (maximum signal level, range of rotation)

Reason for failure for *each* receiver (maximum signal level, range of rotation)

Margin for *each* receiver (maximum signal level)

Multipath energy SDR and relative DTx signal amplitude and delay (maximum signal level, range of rotation)

Calculated individual and total sector angles (range of rotation)

General test site comments (all aspects of the field testing)

In a similar manner, ***one*** separate spreadsheet file was created for the *indoor* data, which followed very closely to the outdoor field test described in the paragraphs above. However, instead of separate worksheets for 30' AGL and 15' AGL receive antennas, two worksheets were described as primary indoor antenna and secondary indoor antenna. The only extra data taken inside the home that was related to unique aspects of the indoor field test was: detailed descriptions of the indoor room location within the building where the testing was performed, and the results of the *smart antenna* testing.

Finally, ***one*** summary spreadsheet file was created to combine selected data into one reference file for quick and easy overview of pertinent data, and printout to hardcopy. A modified version of the summary data can be found in **Appendix 6** (outdoor results) and **Appendix 8** (indoor results).

All four Excel spreadsheet files along with this written report and the plot files (spectrum and RF Watermark analyzers) are available in electronic form from the MTVA.

FIELD TEST SITES

While *indoor* reception was the primary interest in these field tests, a majority of the testing was performed *outdoors* using a directional log periodic antenna situated either 30' AGL or 15 feet AGL due to logistical considerations. In order to obtain a statistically relevant dataset, it was desired to visit within Brooklyn at least a total of **100** *outdoor* ("grid" and "driveway") test sites and at least **20** indoor sites (each indoor site was to be co-sited with one of the outdoor "driveway" sites in order to determine building penetration loss). While more indoor test sites were desired, it was extremely challenging logistically to obtain indoor test volunteers who not only lived in the desired area of Brooklyn (i.e., "within the box" of gap filler transmitters), but who were willing and able to have engineers "invade" their homes with test equipment for an entire weekday. These outdoor and indoor test sites, along with some of their logistical descriptions, are listed in **Appendix 3.** It should be noted that the final set of field test sites visited were slightly different from the ones listed in the original **October 31, 2008** test plan due to various reasons, including, but not limited to, unavailability of access.

Table 5a indicates the number of actual tests performed for each of the 6 test scenarios: 3 RF channels (CH 33, CH 12, CH 65) at 2 antenna heights (30' AGL and 15' AGL) for outdoor testing and 3 RF channels (CH 33, CH 12, CH 65) with 2 antenna types (primary dipole antenna and a secondary directional antenna) for indoor testing. A smart antenna was also tested at each indoor test site. Due to the extremely large number of tests to be performed, each field test crew completed one test site per day. The total number of test sites visited was **132**, but not all tests were able to be performed at each test site due to various reasons such as inclement winter weather, transmitter shutdown, or lack of time at a site before the DTx transmitters and the RF Watermark were turned off at 6 pm. Nevertheless, enough data was taken for statistically relevant outdoor test results.

Table 5a Summary of *visited* MTVA DTx field test sites.

Test Channel #	OUTDOOR						INDOOR	
	Grid Sites (G1)		Interference Sites (IX)		Driveway Sites (HD)		Indoor Sites (HI)	
	30' AGL	15' AGL	30' AGL	15' AGL	30' AGL	15' AGL	Primary	Secondary
CH 33	80	80	6	6	23	23	23	23
CH 12	73	73	6	6	23	23	23	23
CH 65	77	77	6	6	23	23	23	23

It is also important to note that not all of the test sites were located within the main Brooklyn "box". **Table 5b** illustrates that breakdown of test site locations with respect to the "box" as well as by channel tests. It can be seen that a total of **90** *outdoor* test sites were within the "box" while **19** outdoor test sites were outside the "box". Likewise, the *indoor* test sites consisted of **10** inside the "box" and **13** outside the "box."

Table 5b Summary of *visited* MTVA DTx field test sites inside and outside the Brooklyn test "box."

Test CH #	OUTDOOR TEST SITES (109)				INDOOR TEST SITES (23)	
	Inside the "box" (90)		Outside the "box" (19)		Inside the "box" (10)	Outside the "box" (10)
	Grid	**Driveway**	**Interference**	**Driveway**	**Indoor**	**Indoor**
CH 33	80	10	6	13	10	13
CH 12	73	10	6	13	10	13
CH 65	77	10	6	13	10	13

In summary, the MTVA New York City DTS field test began on **January 15, 2008** after all parts of the system (transmit and receive) were installed and confirmed to be operational. The test was performed by two field test crews in two separate field test trucks (each equipped with hydraulic masts capable of 30' AGL extension of the receive antenna). Equipment from the first test vehicle was temporarily removed and used during the indoor testing phase of the project. The field test was completed on **May 9, 2008** after **132** test sites were visited.

OUTDOOR FIELD TEST DATA ANALYSIS

OUTDOOR FIELD TEST OVERIVEW

The purpose of this field test report is to provide the MTVA with the field test results of the New York City prototype Distributed Transmission System. The field test was performed by **MSW** during the months of January, February, March, April, and May of 2008.

The primary goal of the field test and subsequent analysis was to determine the overall success of the DTx network in providing improved urban DTV signal coverage and service to places in the greater metropolitan New York City area (primarily Brooklyn). As stated previously, the primary area of field testing was inside the **3-mile** square Brooklyn "box" formed by the location of the four remote low-power gap filler transmitters. Likewise, another goal of this report was to determine if the DTx network caused interference and no reception to places where the ESB transmitter alone could provide acceptable reception. The summary of the raw *outdoor* data is contained within **Appendix 6.**

General outdoor measurement results that are analyzed in this report include:

(1) DTV Field strength

(2) DTV service

(3) DTV margin

(4) Range of receive antenna rotation

OUTDOOR DTx FIELD STRENGTH EVALUATION

The first consideration in the performance evaluation of the DTx network is *peak* DTV field strength for the "inside the box" Brooklyn outdoor test sites. These sites consisted of all the Grid sites (which by definition are inside the "Box") and some of the Driveway sites (which were matched up with indoor sites, and only some were inside the "Box"). For *each* of the 6 individual tests (3 channels and 2 antenna heights), the antenna was first rotated to determine the azimuth angle at which the *maximum* DTV signal occurs at a given test site. Total *average* DTV signal power (in 6 MHz) was measured at the spectrum analyzer input in each field test truck, and the equivalent root-mean-square (**rms**) field strength (in dBμV/m) was *calculated* using the previously calibrated truck net gain (in dB) from antenna input to spectrum analyzer input. The net truck gain includes the downlead coaxial cable loss (in dB), the variable attenuator loss (in dB), and the preamplifier gain (in dB), plus the known antenna gain over dipole (in dBd) and the dipole conversion factor for each RF channel. Appropriate frequency-dependent parameter values were used for *each* test channel.

Table 6 shows the statistical results of field strength for both DTx OFF and DTx ON for each receive antenna height above ground and for each of the three RF test channels, as well as the amount of *increase* in signal field strength as a result of the DTx network being active. Since all the test sites in this particular analysis are located within the boundaries of the four DTx transmitters, signals from the ESB transmitter and one or more remote gap filler transmitters were expected to be available at each test site.

Note that with DTx *inactive* (i.e., only when the ESB signal was being radiated by itself), the CH 33 signal levels at 30' AGL antenna height averaged around **73 dBμV/m,** with an average increase of about **7 dB** to about **80 dBμV/m** observed when DTx was *active*. Similar test results were obtained at 15' AGL, except that all the values were about **3 dB** lower in value.

CH 12 likewise experienced a significant field strength *increase* when DTx was active, except that the increase was slightly *higher (≈11 dB)*. However, the CH 12 average field strengths with DTx *inactive* (≈**59 dBµV/m**) and DTx *active* (≈**70 dBµV/m**) were lower values than its CH 33 UHF counterparts since relatively much less power was transmitted on CH 12 from ESB as well as from the low-power gap filler transmitters. Note that higher signal levels are not required for a VHF channel like they are for UHF channels due to the frequency-dependent dipole effect that more effectively converts field strength to output voltage in viewers' receive antennas.

CH 65, which is measured with only DTx-*active* since there was no CH 65 transmitter on ESB, had field strengths around **75 dBµV/m**, which were a few dB *less* that that observed on CH 33.

Also note that the difference in the *average* peak field strengths between the 30' AGL and 15' AGL receive antenna heights was only about **2 – 3 dB** on CH 33 and CH 12, with or without DTx.

Table 6 Inside the "box" *peaked* DTV field strength site statistics.

DTx Status	CH 33		CH 12		CH 65		Units
	30'	15'	30'	15'	30'	15'	
DTx OFF	72.7	69.9	58.9	56.7	N.A.	N.A.	dBµV/m (ave)
	73.7	70.3	58.0	56.7	N.A.	N.A.	dBµV/m (med)
	9.6	8.9	8.5	7.9	N.A.	N.A.	dBµV/m (std dev)
DTx ON	80.2	77.1	69.7	66.7	76.0	73.8	dBµV/m (ave)
	79.3	77.6	70.6	66.2	75.7	73.2	dBµV/m (med)
	7.8	7.6	8.7	8.8	8.9	8.2	dBµV/m (std dev)
Field Strength Increase	7.5	7.2	10.8	10.0	N.A.	N.A.	dBµV/m (ave)
	4.0	4.4	8.2	8.4	N.A.	N.A.	dBµV/m (med)
	9.0	8.5	10.2	10.0	N.A.	N.A.	dBµV/m (std dev)

The distribution of field strengths can be displayed graphically in a probability density function (**PDF**), sometimes referred to as a histogram, and its associated cumulative distribution (**CDF**). Such graphs were created and plotted for all the Brooklyn "box" measured field strength values obtained with the antenna "peaked" for maximum signal, and they are shown in **Figure A7-1** through **Figure A7-12** in **Appendix 7**. These plots visually describe the spread of the observed field strength levels measured at each test site both with and without DTx active. PDF and CDF plots were individually generated for CH 33, CH 12, and CH 65 (where applicable) at each of the two antenna heights. From these graphs, the statistical variations of field strength over all the test sites visited can be viewed, especially the comparison between DTx OFF and DTx ON for CH 33 and CH 12.

The break down of the site percentages by the amount of field strength *increase* created by the DTx network is shown in **Table 7**. Of course, CH 65 is not included in this analysis since there was no CH 65 transmitter on ESB with which to compare. It was expected that most Brooklyn "box" test sites would exhibit some increase in field strength when DTx was active. Note that CH 33 has at least some field strength increases ($\Delta FS > 0$ dB) at over **80%** of the test sites compared to CH 12 at over **90 %** of the test sites. CH 12 has a larger increase due to the fact that the CH 33 ESB radiated signal is relatively larger (137 kWatt ERP) compared to its remote transmitters' radiated signals (1 kWatt ERP) than the CH 12 ESB radiated signal (1 kWatt ERP) compared to its remote transmitters' radiated signals (100 Watt ERP). Therefore, CH 12 signals would be expected to experience a larger increase with DTx active. Also note that over **30%** of the test sites experienced a 10 dB or greater increase in field strength due to the DTx system. The extra signal strength at these sites may aid with indoor DTV reception by helping to overcome the signal loss due to lower gain receive antennas at lower heights above ground level as well as building penetration loss.

Table 7 Inside the "box" DTx- increased *peaked* field strength site percentages

Field Strength Increase	CH 33		CH 12		CH 65		Units
	30'	15'	30'	15'	30'	15'	
ΔFS > 0 dB	72	78	78	78	N.A.	N.A.	sites
	90	90	83	83	N.A.	N.A.	sites, total
	80.0	86.7	94.0	94.0	N.A.	N.A.	%
ΔFS > 10 dB	29	28	38	33	N.A.	N.A.	sites
	90	90	83	83	N.A.	N.A.	sites, total
	32.2	31.1	45.8	39.8	N.A.	N.A.	%
ΔFS > 20 dB	10	7	17	12	N.A.	N.A.	sites
	90	90	83	83	N.A.	N.A.	sites, total
	11.1	7.8	20.5	14.5	N.A.	N.A.	%

Related to field strength is the signal-to-noise ratio (**SNR**) that is present at the input to the DTV receiver. It is this ratio of signal power to noise power (both measured in 6 MHz) that determines if the DTV signal is above the white noise threshold of visible (**TOV**) errors for the VSB transmission system, and whether it can be decoded error free. In this MTVA field test, the SNR was determined by the received signal strength and the truck's system noise floor. The noise floor in the truck (i.e., the WIAD) was determined by the low-noise preamplifier that was in the signal path for amplification and splitting of the received signal. The preamplifier itself effectively had a 4 dB noise figure, but when coupled with a 3-dB pad present at its front end, the total truck noise figure was the same as the 7 dB UHF noise figure found in the FCC planning factors (OET Bulletin 69).

The 8-VSB digital transmission system has a well-known *Gaussian* white noise SNR threshold of visible errors around 15 dB, assuming there is no interference or other impairments present. However, this 15 dB SNR threshold value may be degraded (i.e., increased) in *severe* propagation conditions experienced in the field (such as multipath) by as much as 5 - 8 dB. Therefore, knowledge about the SNR values statistically encountered at the field test sites is important. **Table 8** contains the site statistics while **Table 9** contains the site percentages.

Note that the average SNR values in **Table 8** were quite high (**>35 dB**) with DTx inactive and even higher (**7 – 10 dB**) when DTx was active due to the much larger received signal levels. Naturally, SNR was slightly lower for the 15' AGL antenna measurements due to the slightly lower field strengths at the lower receive antenna heights.

Table 8 Inside the "box" SNR site statistics.

DTx Status	CH 33		CH 12		CH 65		Units
	30'	15'	30'	15'	30'	15'	
DTx OFF	43.0	40.2	38.7	36.4	N.A.	N.A.	dBµV/m (ave)
	44.2	40.9	37.4	36.6	N.A.	N.A.	dBµV/m (med)
	9.8	9.0	8.7	8.0	N.A.	N.A.	dBµV/m (std dev)
DTx ON	50.5	47.4	49.4	46.4	42.6	40.4	dBµV/m (ave)
	50.3	47.5	49.8	46.1	41.9	39.6	dBµV/m (med)
	7.9	7.5	8.8	8.8	8.8	8.0	dBµV/m (std dev)
SNR Increase	7.5	7.2	10.8	10.0	N.A.	N.A.	dBµV/m (ave)
	4.0	4.4	8.2	8.4	N.A.	N.A.	dBµV/m (med)
	9.0	8.5	10.2	10.0	N.A.	N.A.	dBµV/m (std dev)

Of particular interest is the *distribution* of SNR values compared to the 15-dB white noise threshold. From **Table 9**, note that ***every*** test site with or without DTx active had a measured SNR value greater than 15 dB, and thus theoretically capable of successful DTV reception (in a white Gaussian propagation environment). There were very few sites (< **7%**) that had SNR values between 15 and 23 dB with DTx inactive, but all the test sites had SNR > 23 dB with DTx active. However, two things must be remembered about this fact. First, these are outdoor measurements at 30' and 15' using a *directional* antenna that is adjusted for *maximum* signal level. One would expect a greater probability of large received signal levels and thus large SNR values. Second, these tests sites within the Brooklyn grid were typically less than 10 miles away from any one of the five transmitters (ESB and 4 remote gap filler transmitters), and quite often less than 5 miles away. Therefore, large SNR values would be expected during this testing, and they were, in fact, observed.

Another important issue is the fact that despite the relatively strong signals measured at each test site, limited DTV reception is still possible due to severe *naturally-occurring* multipath (DTx OFF or DTx ON) and/or due to severe *DTx-induced* multipath (DTx ON). That is, a minimum signal level that provides SNR values above 15 dB is a necessary, but not sufficient, condition for successful DTV reception. For outdoor measurements, the receive *antenna directivity* plays a vital role as does the *equalizer performance* of the DTV receiver. However, these are even more important for indoor reception. Nevertheless, this field test confirmed that there was ample signal level for outdoor reception where the antenna was pointed in the direction of maximum signal level.

Since equalizer white noise enhancement can occur in DTV receivers under severe propagation conditions (e.g., strong multipath), the breakdown in **Table 9** is helpful to see that almost all of the test sites (**> 93%**) had more than 8 dB of excess SNR over the 15 dB white Gaussian noise threshold *without* DTx and all of them (**100%**) had at least 8 dB (and often more) of excess SNR *with* DTx active. However, it must be remembered that signal strengths measured in the field are a net total of *all* received signals from all the transmitters, and therefore, successful reception depends on the ability of the DTV receivers to remove the effects of the naturally-occurring multipath from the urban clutter or the self-induced multipath from multiple synchronized signals.

Table 9 Inside the "box" SNR site percentages

DTx Status	SNR Range	CH 33		CH 12		CH 65		Units
		30'	15'	30'	15'	30'	15'	
DTx OFF	SNR > 15 dB	90	90	83	83	N.A.	N.A.	sites
		90	90	83	83	N.A.	N.A.	sites, total
		100.0	100.0	100.0	100.0	N.A.	N.A.	%
DTx OFF	SNR > 23 dB	86	87	80	77	N.A.	N.A.	sites
		90	90	83	83	N.A.	N.A.	sites, total
		95.6	96.7	96.4	92.8	N.A.	N.A.	%
DTx OFF	SNR > 15 dB and SNR < 23 dB	4	3	3	6	N.A.	N.A.	sites
		90	90	83	83	N.A.	N.A.	sites, total
		4.4	3.3	3.6	7.2	N.A.	N.A.	%
DTx ON	SNR > 15 dB	90	90	83	83	87	87	sites
		90	90	83	83	87	87	sites, total
		100.0	100.0	100.0	100.0	100.0	100.0	%
DTx ON	SNR > 23 dB	90	90	83	83	87	87	sites
		90	90	83	83	87	87	sites, total
		100.0	100.0	100.0	100.0	100.0	100.0	%
DTx ON	SNR > 15 dB and SNR < 23 dB	0	0	0	0	0	0	sites
		90	90	83	83	87	87	sites, total
		0.0	0.0	0.0	0.0	0.0	0.0	%

Finally, in any DTx network consisting of two or more remote gap filler transmitters, the *largest* signal received at each test site in an overlapping coverage region is of interest to DTS designers. **Table 10** illustrates the percentages of sites for which each of the 5 transmitters (or 4, in the case of CH 65) was the largest signal when DTx was *active* and when the receive antenna was oriented for maximum total signal strength. It can be seen that Transmitter A at 16 Court Street is the predominant transmitter among the four remote low-power gap filler transmitters, most likely due to its higher elevation compared to the other gap filler transmitters.

On CH 33 at 30' AGL with DTx active, the ESB transmitter and gap-filler transmitter A (which was on the tallest building of the 4 remote transmitters) had a comparable number (**≈40%** each) of tests sites where each was the largest signal. However, for CH 33 at the lower receive antenna height of 15' AGL, the ESB signal was predominant over gap-filler transmitter A by about **10%**. This is most likely due to the much taller ESB transmit antenna playing a larger role at the lower receive antenna height given more urban obstacles (i.e., buildings) to attenuate the DTV signal. For CH 12, however, transmitter A was by far (**2-to-1** advantage over ESB at 30' AGL) the largest signal since the CH 12 ESB transmitter was not as relatively strong as its CH 33 counterpart. Transmitters B, C, and D had a negligible percentage (**≈10%** or less) of sites where they were the largest signal. However, it must again be pointed out that these results are taken from *outdoor* measurements at 30' AGL and 15' AGL while using a *directional* receive antenna pointed in the direction of maximum signal. Conditions inside a viewer's home were not identical (see the indoor field test results section).